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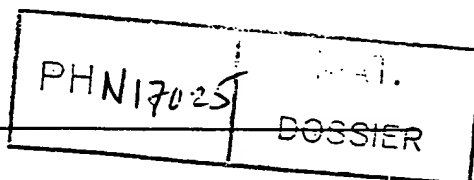
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(54) Method for counteracting geometric distortions for DCT based watermarking

(57) In order to compensate for geometric distortion when extracting a watermark from watermarked data, the geometrically distorted data undergoes cyclic rotation of the pixels in groups of 8x8 pixel blocks to remove any geometric distortion.

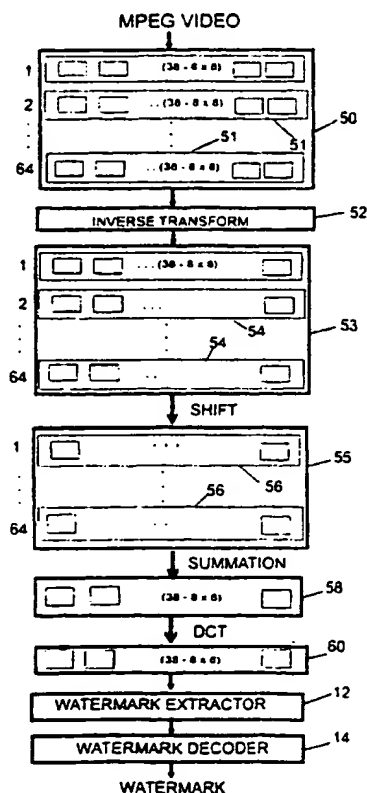


FIGURE 5

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Description

[0001] The present invention relates to digital watermarking of multimedia data and particularly video data. More particularly, the invention concerns watermarking of compressed video data, such as JPEG and MPEG, and the detection of a watermark in compressed video that has been subject to geometric distortion.

[0002] The proliferation of digitized media such as image, video and multimedia is creating a need for a security system which facilitates the identification of the source of the media. The expected introduction of digital video disks (DVD) in mass markets will further exacerbate the problem.

[0003] Content providers, i.e. owners of works in digital data form, have a need to embed signals into video/image/multimedia data, including audio data, which can subsequently be detected by software and/or hardware devices for purposes of authenticating copyright ownership, control and management.

[0004] There are systems for inserting a watermark into digital media and for extracting a watermark from watermarked media. Typical systems may comprise

spread spectrum watermarking by embedding a watermark signal in perceptually significant regions of an image for the purposes of identifying content owner and/or possessor. An article entitled "Secure Spread Watermarking for Multimedia" by Cox et al available at <http://www.neci.nj.nec.com.tr/index.html> (Technical Report No. 95-110) describes spread spectrum watermarking which embeds a pseudo-random noise sequence into digital data for watermarking purposes.

[0005] The above watermark extraction methodology requires the original image spectrum be subtracted from the watermarked image spectrum. This restricts the use of the method when there is no original image or original image spectrum available to the decoder.

[0006] In U.S Patent No. 5,319,735 by R.D. Preuss et al entitled "Embedded Signaling" digital information is encoded to produce a sequence of code symbols. The sequence of code symbols is embedded in an audio signal by generating a corresponding sequence of spread spectrum code signals representing the sequence of code symbols. The frequency components of the code signal being essentially confined to a preselected signaling band lying within the bandwidth of the audio signal and successive segments of the code signal corresponds to successive code symbols in the sequence. The audio signal is continuously frequency analyzed over a frequency band encompassing the signaling band and the code signal is dynamically filtered as a function of the analysis to provide a modified code signal with frequency component levels which are, at each time instant, essentially a preselected proportion of the levels of the audio signal frequency components in corresponding frequency ranges. The modified code signal and the audio signal are combined to provide a composite audio signal in which the digital information is embedded. This component audio signal is then recorded on a recording medium or is otherwise subjected to a transmission channel. Two key elements of this process are the spectral shaping and spectral equalization that occur at the insertion and extraction stages, respectively, thereby allowing the embedded signal to be extracted without access to the unwatermarked original data.

[0007] In a system for a spread spectrum watermark for embedded signaling, a watermark or embedded data are extracted from watermarked images or video without using an original or unwatermarked version of the data.

[0008] This method of watermarking an image or image data for embedding signals requires that the DCT (discrete cosine transform) and its inverse of the entire image be computed. There are fast algorithms for computing the DCT in $N \log N$ time, where N is the number of pixels in the image. However, for $N=512 \times 512$, the computational requirement is still high, particularly if the encoding and extracting processes must occur at video rates, i.e. 30 frames per second. This method requires approximately 30 times the computation needed for MPEG-II decompression.

[0009] One possible way to achieve real-time video watermarking is to only watermark every N^{th} frame. However, content owners wish to protect each and every video frame. Moreover, if it is known which frames contain embedded signals, it is simple to remove those frames with no noticeable degradation in the video signal.

[0010] An alternative option is to insert the watermark into $n \times n$ blocks of the image (subimages) where $n \ll N$. If the block size is chosen to be 8×8 , i.e. the same size as that used for MPEG image compression, then it is possible to tightly couple the watermark insertion and extraction procedures to those of the MPEG compression and decompression algorithms. Considerable computational saving can then be achieved since the most expensive computations relate to the calculation of the DCT and its inverse and these steps are already computed as part of the compression and decompression algorithm. The incremental cost of watermarking is then very small, typically less than five percent of the computational requirements associated with MPEG.

[0011] This system may be further advanced by using MPEG/JPEG coefficients to encode the image data.

[0012] Furthermore, watermark information may be stored into and extracted from subimages.

[0013] A review of watermarking is found in an article by Cox et al., entitled "A review of watermarking and the importance of perceptual modeling" in Proc. of EI'97, vol. 30-16. February 9-14, 1997.

[0014] To allow for computationally efficient detection of the watermark in both the spatial and DCT domains, a water-

mark is inserted into sums of groups of 8x8 blocks in the DCT. The advantage of this approach is that, if the image is only available in the spatial domain, then the summation can also be performed in the spatial domain to compute a small number of 8x8 blocks and only these blocks must then be transformed into the DCT domain. This is because the sum of DCT blocks is equal to the DCT of the sum of spatial blocks. Since the computational cost of detecting watermarks is now dominated by the cost of summation, the cost of detecting in the DCT and spatial domains is approximately the same.

[0015] Although these watermarking techniques are highly successful, there is one problem remaining. Namely, even small geometric changes to an image or video frame significantly affects the DCT coefficients. For example, consider an image that is divided into 8 x 8 blocks and transformed into the frequency domain by computing the DCT of the blocks. If the image is now reduced in size by 1/8, then each original 8 x 8 pixel block is reduced to a set of 7 x 7 pixels. If the reduced or scaled image is again divided into 8 x 8 blocks and the corresponding DCTs of the blocks are calculated, these new DCT coefficients are usually very different from those of the original unscaled image. As a result, watermark detection often fails.

[0016] The present invention solves the problem of geometric scaling or affine distortion of images or video frames by approximating the scale change or distortion by a spatially varying translation of each 8 x 8 block. The image is divided into a disjoint set of blocks, each block within a set experiencing the same translation. The set of blocks is different for different sets. The watermark is extracted for all translations of the blocks and the maximum correlator output is tested for statistical significance in order to determine whether a watermark is present in the image or video frame.

[0017] A watermark algorithm divides an image or video data into 8 x 8 pixel blocks. The blocks are then apportioned among 38 groups. The watermark detection process begins by summing all 8 x 8 blocks in a group, thereby reducing the dimension of the data into 38 blocks of 8 x 8 values each. A subset of coefficients in each of the 8 x 8 blocks is further summed together to form a one-dimensional vector of length 38.

[0018] The 38 groups of 8 x 8 blocks of DCT coefficients are chosen in such a way that translation shifts of multiples of 8 pixels simply result in a cyclic rotation of the extracted 1-D watermark vector. For shifts that are not a multiple of 8, it is only necessary to determine the translation remainder modulo 8, i.e. translation of 0 to 7 pixels in both the x and y directions. This is accomplished by taking the 38-8 x 8 blocks of DCT coefficients and first transforming them to the spatial domain. Next, the data is shifted by one of the 64 possible translations before being transformed back to the DCT domain. The watermark is then extracted and tested as will be described below. The process is repeated for all translations and the maximum value of the correlator output is then tested for statistical significance in order to determine whether a watermark is present.

[0019] Since the amount of translation of the image or video frame is not known beforehand, by repeating the shift for all translations of 0 to 7 pixels, and then determining the signal with the highest correlation to a watermark, the most likely translation factor and watermark are determined.

[0020] The present invention approximates geometric distortions by spatially varying translations. While removing the change or distortion from the image or video data is extremely difficult, manipulation in the form of spatial translation of blocks is a relatively simple way to extract a watermark from the distorted image or video, without restoring the image or video to its original, undistorted condition.

[0021] A principal object of the present invention is therefore, the provision of a watermark detection method which corrects for affine distortion of the watermarked data, such as image or video data.

[0022] Further objects of the invention will become more clearly apparent when the following description is read in conjunction with the accompanying drawing.

Figure 1 is a flow diagram of a watermark detection procedure for the case where a stream of compressed video is input;

Figure 2 is a flow diagram of a watermark detection procedure for the case where uncompressed data is the input;

Figure 3 is a representation of a scaled sequence of blocks relative to an original sequence of blocks;

Figure 4 is a schematic representation of a set of eight accumulator arrays;

Figure 5 is a flow diagram of a preferred embodiment of the invention when compressed video is input; and

Figure 6 is a flow diagram of a preferred embodiment of the invention when uncompressed video is input.

[0023] As used in the following description the terms image, image data, video, video frame and video data will be understood to apply equally to video, image and multimedia data. The term "watermark" will be understood to include embedded data, symbols, images, instructions or any other identifying information.

[0024] A significant problem in designing a watermarking system and particularly for DVD applications is to insert watermarks that are easy to detect in both MPEG compressed and uncompressed video. Most watermarks can be easily detected in either the spatial (uncompressed) or the DCT (compressed) domains, but not both. This means that detecting the watermarks in one or the other domain requires conversion of the entire image, which is generally too computationally expensive for DVD applications. In the following description, it is assumed that a watermark was

inserted into the video data in a conventional manner, for example in a manner described in patent applications and publications cited above.

5 [0025] A solution to the problem is to insert the watermark in such a way that it can be extracted from a small number (or groups) of 8×8 blocks, preferably 38 groups. Each group is the sum of many blocks in the image. If 8×8 blocks in the spatial domain are added together in a group, and then the DCT of the sum is computed, it is the equivalent of computing the DCT of each block and adding the DCTs together. The DCT of the sum of the 8×8 blocks in a group in the spatial domain is the equivalent of the sum of the DCT of each 8×8 block in the group. The result is that the 38 summed blocks can be computed directly from either uncompressed or MPEG encoded data, with conversion into the spatial or compressed domain being performed only after the summation is performed. Thus, rather than computing 5400 DCT coefficients, only 38 DCTs are computed.

[0026] The size of blocks is preferably selected to be 8×8 because of the structure of common MPEG video signals. However, the invention is applicable to any $n \times n$ block. The number of groups arbitrarily is selected to be 38. The invention can use other quantities of groups of blocks. Therefore, in the following description when reference is made to 38 items, it will be understood that any predetermined number of items could be used.

15 [0027] Referring now to the figures and to Figure 1 in particular, there is shown a flow diagram of a watermark detection procedure for the case where an MPEG stream of compressed video is input. As each 8×8 block of DCT coefficients is decoded from the input stream, it is added in one of 38 - 8×8 accumulators 10(1), 10(2) ... 10(38). After the entire image has been added into the 38 - 8×8 accumulators, the watermark is extracted from the 38 accumulators resulting groups in a conventional manner 12. The extraction process is simple, requiring only about 500 addition operations. Finally the extracted watermark is decoded 14 and statistically tested to determine if the extracted signal is a real watermark, or merely noise present in an unwatermarked image. If it is determined that a watermark actually is present, the watermark may be decoded to yield information bits necessary for DVD applications. The input video is added to a particular accumulator based on a predetermined mapping relationship used when the watermark was inserted into the video stream.

25 [0028] Figure 2 shows the corresponding watermarking detection procedure for the case where the input is a stream of uncompressed data or uncompressed video. As each pixel arrives, it is added to one of 38 - 8×8 accumulators 20 according to a predetermined mapping algorithm corresponding to the algorithm used when inserting the watermark into the video. After the entire image has been added into the accumulators, the DCT values of the accumulated video is calculated 22 and the remainder of the watermark decoding process proceeds as described in conjunction with the receipt of MPEG video shown in Figure 1.

30 [0029] The general methods described above in conjunction with Figures 1 and 2 work very well as long as the partitioning of the images into 8×8 blocks during distortion is identical to the partitioning used when the watermark was inserted. However, if the image was subjected to geometric or other affine distortion, the watermark becomes difficult to detect.

35 [0030] In order to counteract such distortions, the above watermark detection processes are modified. Consider, an image that has been reduced by one-eighth in the horizontal direction. Referring to Figure 3, the lower row of boxes shows the spatial position of a sequence of 8×8 blocks, 1, 2, 3, ... 9, in the original image and the upper row of boxes shows the positions of the 8×8 blocks, 1', 2', 3', ... 10', after the original image has been reduced or scaled by a scale factor. Block 1 in the original image has a strong overlap with block 1' in the scaled image. Block 2 in the original image shares 6 columns of 8×8 pixels with block 2', having been shifted by 1 pixel relative to block 2. Thus, if the columns of block 2' were shifted one column to the right before computation of its DCT, the result would be quite similar to the DCT of the original block 2. The difference between the scaled and original blocks is entirely due to the fact that column 1 of block 2' coincides with column 8 in block 1. This is a source of additional noise for the watermark detector.

40 [0031] Block 1' in the scaled image only differs by a single column of pixels from its corresponding block 1 in the original image. However, Block 5' only has 4 columns in common with block 4 in the original image. Moreover, 4 columns of block 5' are not common to block 4 and 4 columns of block 4 are not common to block 5'. Consequently, block 5' is a very noisy approximation to block 4, even after compensation for the relative shift in translation.

45 [0032] Considered in this manner, scale changes can be approximated by a spatially varying translation of the 8×8 blocks of the scaled image. Therefore the watermark extraction process is modified to achieve this result. The single array of 38 accumulators is replaced by a set of 8 such accumulator arrays for the one-dimension (1-D) horizontal shifts. For two-dimension (2-D) translation, 8×8 or 64 accumulator arrays are necessary. Only 8 arrays are necessary since multiples of 8 result in cyclic shifts of the extracted watermark.

50 [0033] Figure 4 shows a set of 8 accumulator arrays, each associated with a translation of a predetermined number of columns. During the accumulation phase of the extraction procedure, the 8×8 Block 1' is added to accumulator 1 of set 40, the 8×8 Block 2' is added to accumulator 2 of set 42, Block 3' to accumulator 3 of set 43, and block 4' to accumulator 4 of set 44. Block 5' shares equal amounts of data with both Blocks 4 and 5. Thus Block 5' is added to either accumulator 4 or 5 of set 44 depending upon the rules used to direct the blocks to respective accumulators. Block 6' is added to accumulator 5 of set 45 and so forth. The rules regarding where the blocks are added are a function of the

assumed scaling. That is, the accumulators are chosen to provide the necessary spatial translation in order to compensate for the assumed or known scale distortion.

5 [0034] After completing the accumulation of the 8×8 blocks in each accumulator of sets 41 through 47, the summed data are transformed from the DCT domain into the spatial domain and shifted by one column (set 41), two columns (set 42) and so forth, respectively before the spatial domain data is transformed back into the DCT domain. Now, the relative translational shift has been removed and the data in the corresponding accumulators in the set of eight accumulator arrays 40 to 47 are added together to form a single (one-dimension) accumulator array of $38 \times 8 \times 8$ blocks. Watermark extraction then proceeds as described above.

10 [0035] Figure 5 shows the process when compressed video is input and Figure 6 shows the process when uncompressed video is input.

[0036] In Figure 5, the input compressed video, e.g. MPEG video, is placed into the array 50 of accumulators 51. Each accumulator 51 comprises $38 \times 8 \times 8$ blocks. There are 64 such accumulators to compensate for two-dimensional translation. The contents of the 64 accumulators 51 undergo an inverse transform 52 into the spatial domain and are placed into an array 53 of 64 accumulators 54. Each accumulator 54 comprises $38 \times 8 \times 8$ blocks. The data in the array 53 undergoes shifting (translation) as described above to compensate for a known or assumed geometric distortion. The shifted data are summed in array 55 comprising 64 accumulators 56. Each accumulator 56, in turn, comprises $38 \times 8 \times 8$ blocks of data in the spatial domain. The corresponding blocks in each accumulator 56 are summed together into a one-dimension array of $38 \times 8 \times 8$ blocks 58. The summed data is subject to a discrete cosine transform and the DCT values are stored in accumulator array 60. The resulting summed DCT data in the single accumulator 60 of $38 \times 8 \times 8$ blocks is subjected to watermark extraction 12 and watermark decoding 14 as described above, in conjunction with Figure 1.

25 [0037] Experimental tests show that almost equivalent results can be obtained using only data from a subset of the accumulators in array 50, 53, 55, for example, using the data in the shift 0, 1, 6 and 7 accumulator arrays (40, 41, 46 and 47) and disregarding the data in the other accumulators. This results in a significant memory saving. A further improvement is gained by using a coarser quantization of shifts such that the first accumulator array contains data that has been shifted by 0 or 1. Similarly, accumulator array 2 handles shifts of 2, and 3, etc.

30 [0038] In Figure 6, the uncompressed video is added in an array 64 of $38 \times 8 \times 8$ accumulators 65 based on a look-up table 62 that sends the incoming video pixels to a particular accumulator according to a mapping corresponding to the assumed geometric distortion to which the watermark video has been subjected. The summed data in the accumulators 65 are converted into DCT coefficients. The DCT coefficients are summed in a one-dimension array 66 of $38 \times 8 \times 8$ block accumulators 67. The data in the accumulator 66 is subjected to watermark extraction and watermark decoding as described above.

[0039] While the above description refers to horizontal or column shifts, it will be apparent to those skilled in the art that the same process is equally applicable to vertical or row shifts or to a combination of row and column shifts.

35 [0040] The above example assumed that the reduced scale of the image is known. A different scale requires a different association of scaled blocks to the accumulator arrays. However, this is straightforward to compute.

[0041] A further reduction in memory can be achieved by spreading the computation over many frames. In this manner, only a single accumulator array is needed. In frame 0 blocks with shift 0 are accumulated. At the end of frame 0 the accumulator shifts by 1 so that in frame 1, blocks shifted by 1 are accumulated. Thus, after 64 frames, the same result is obtained as earlier, requiring only $1/64$ of the memory.

40 [0042] The pseudocode for performing the shifts is as follows:

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g = "scaling group" (i.e. the number of sets of 38 accumulators used)

5 sx = 0

sy = 0

For each of g frames

{

10 Add ONLY the blocks that must be shifted by sx pixels to the right and sy pixels upward into the single set of 8 x 8 accumulators. Ignore all the other blocks.

Compute IDCTs on the accumulators.

15 Shift the accumulators left one pixel.

sx = (sx + 1) ÷ 8

if (sx == 0)

{

20 Shift the accumulators down one pixel.

sy = (sy + 1) ÷ 8

}

25 Compute DCTs on the accumulators.

}

30 [0043] In practice, the scale or geometric distortion is not known, or the scale is not a integer number of columns (or rows), although the range of scales of interest often is known. For example, in video it is assumed that the scale may vary by $\pm 5\%$ and is fixed for the duration of a movie (sequence of video frames), or at least for extended periods of a movie. This latter assumption is reasonable, since if the scale changes frequently, the perceived video quality would be degraded. In these circumstances, a search process must be initiated in which the watermark detector attempts to

35 determine the amount of scaling. For the example of $\pm 5\%$ in both the horizontal and vertical directions, there are 11 x 11 possible scales, if the scaling is quantized in unit intervals. "Unit intervals" refers to the fact that if the reduction is not 1/8, 1/4, 3/8, 1/2, 5/8, 3/4, or 7/8, then the overlap will not coincide with an integer number of rows or columns. In that case, the translational shift will be "rounded" to an integer number of rows or columns. If 2 seconds is needed to detect a watermark at a fixed scale, then 2 x 121 = 242 seconds are needed to search all possible scales. This can be consid-

40 ered the worst case latency. In practice, the average latency will be much less, particularly of an intelligent search procedure is used which search most likely scales first.

[0044] Scale is not the only geometric distortion that may be approximated by a spatially varying translation of the 8 x 8 DCT blocks. Other affine transforms can also be handled similarly.

45 Claims

1. A method for extracting a watermark from watermarked compressed data comprising the steps of:

50 receiving watermarked compressed data in the form of n x n blocks of data;
spatially translating the blocks to compensate for geometric distortion; and
extracting a watermark from the translated data.

2. A method of extracting a watermark from watermarked compressed data comprising the steps of:

55 receiving watermarked compressed data in the form of 8 x 8 blocks;
accumulating said blocks in a set of a predetermined number of groups of 8 x 8 blocks;
converting the accumulated blocks into spatial domain;
spatially translating the spatial domain accumulated blocks to compensate for an assumed affine distortion;

summing the translated blocks; and
extracting a watermark from the translated blocks.

3. A method of extracting a watermark from watermark as set forth in claim 2 where said extracting a watermark comprises calculating discrete cosine transform values of the summed blocks.
4. A method of extracting a watermark from watermark as set forth in claim 2 or 3 where said steps are repeated for different assumed affine distortions.

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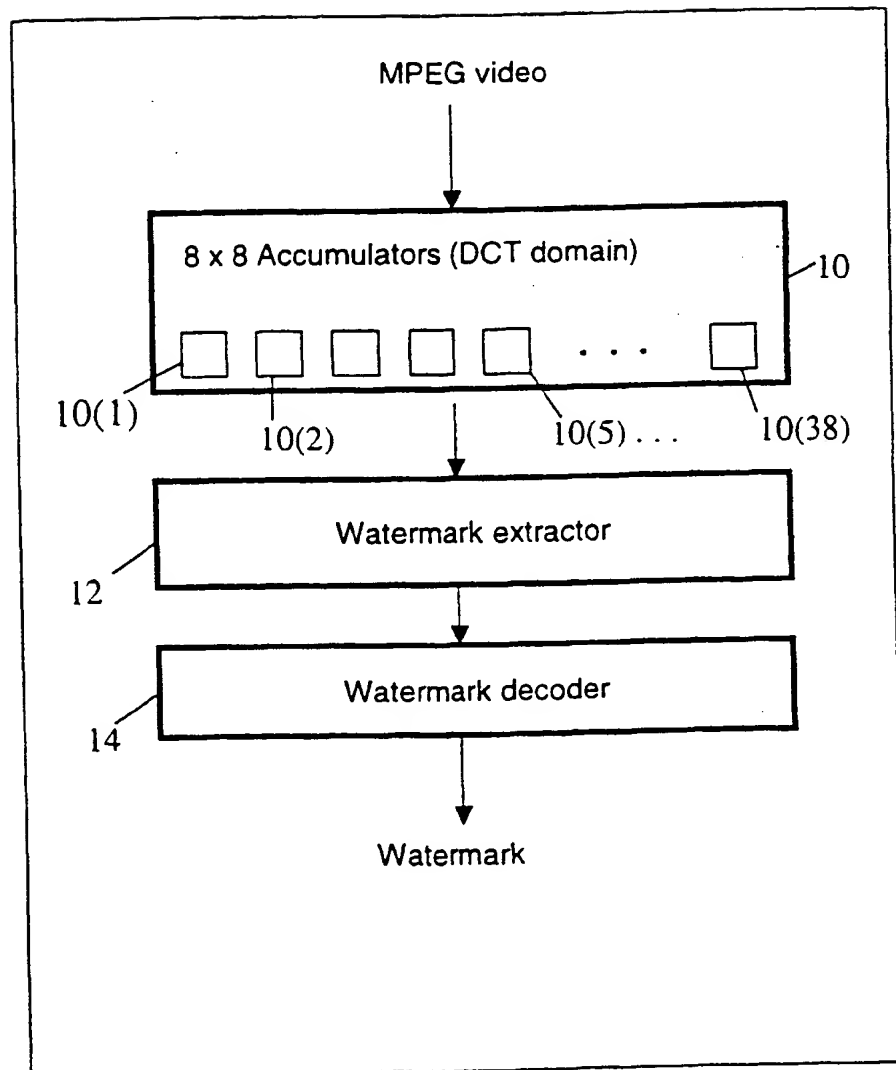


FIGURE 1

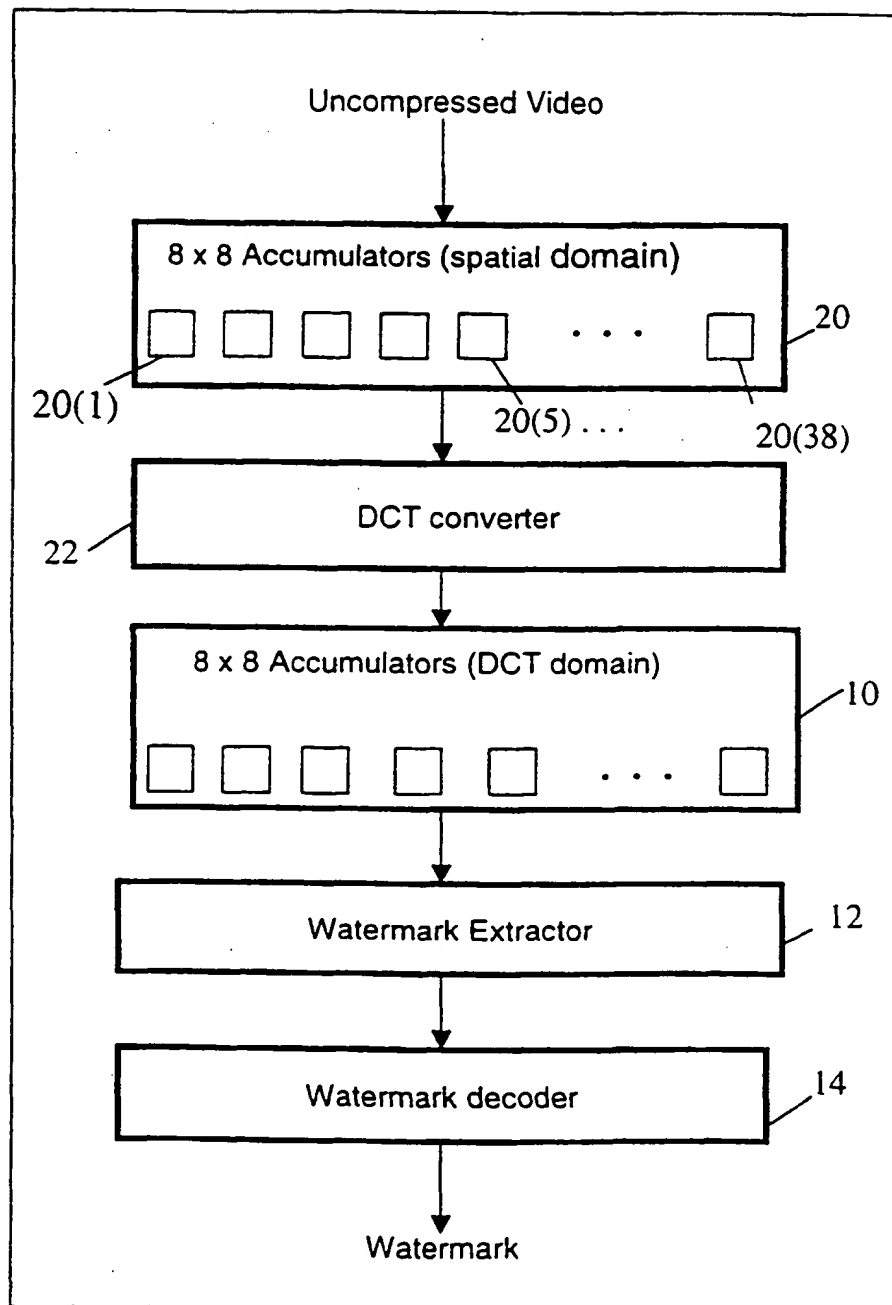


FIGURE 2

Scaled	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	
Original	1	2	3	4	5	6	7	8	9		

FIGURE 3

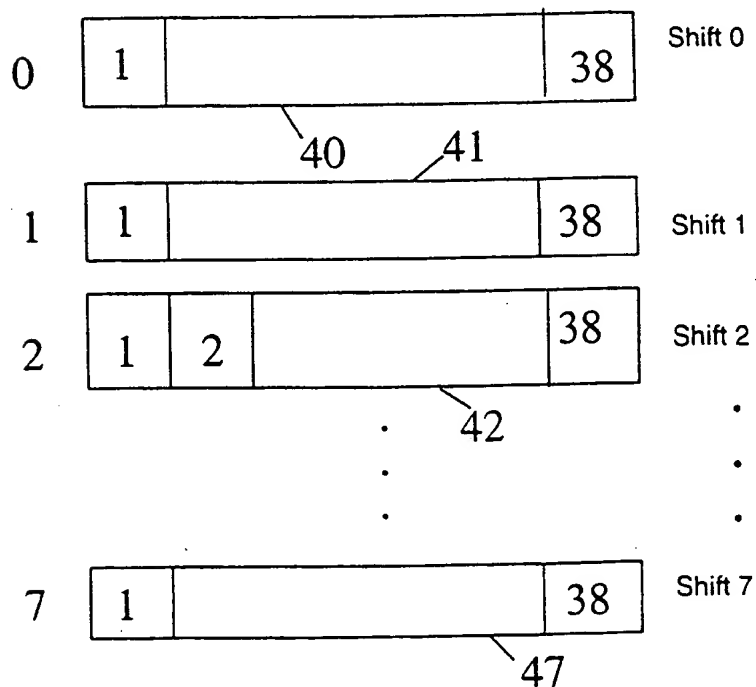


FIGURE 4

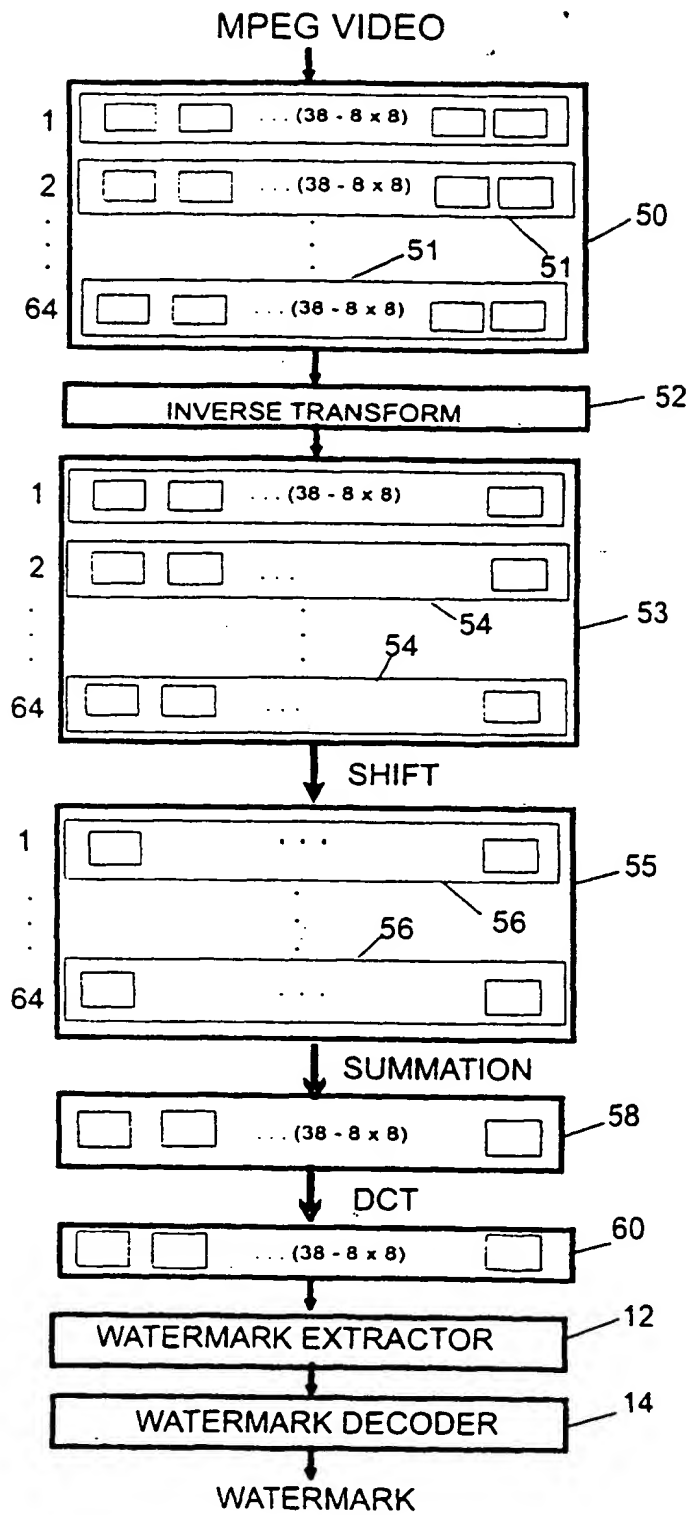


FIGURE 5

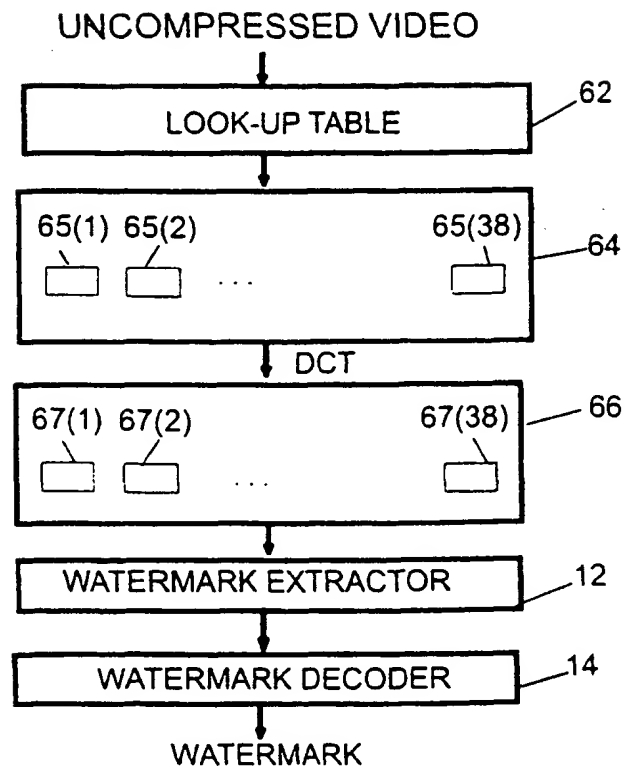


FIGURE 6